A CHANGE OF MESOSPHERIC OZONE CONTENT UNDER ELECTRON PRECIPITATION INFLUENCE

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The simulation model of a change of O, O_2 and O_3 oxygen component content at the heights 50 - 140 km under electron precipitation influence is presented here. Parameters of the air mass vertical transfer are introduced into the model. Calculation results showed that after the intense precipitation in ~ 3 days the ozone content increased at heights ~ 80 km. These results agree with the experimentally found effects of the content change under precipitation conditions.

Introduction

The experiments during solar proton events (HEATH, 1977; LIPPER, 1985; THOMAS, 1983) show a decrease of ozone content at the flare initial phase. A further behaviour of ozone concentration in the stratosphere and mesosphere differ from each other. For example, a total ozone number at height ~ 37 km after the August 1972 proton flare (HEATH et al., 1977) did not recover for several weeks. In the mesosphere the ozone concentration recovery up to its initial values occurred within a short time and then the further growth of $[O_3]$ in some events was observed. During the solar proton events in July and September 1974 (LIPPER et al., 1985) at 80 km the difference between the proton flux maximum and the ozone density minimum is ~ 36 hours and the maximum ozone content is observed in 4 - 6 days after the flare maximum. For the first time, a possibility of ozone concentration increase at heights between 70 and 85 km was theoretically predicted by CRUTZEN (1980) by an example of the solar flare in August 1972. The ozone content increase after the intensive precipitation of high energy electrons on March 23, 1974 (SKRYABIN et al., 1977) is shown. In this case the electron precipitation with average energy 250 keV occurred as three splashes each of them lasted 15 - 30 min. At this time at 120 - 200 km height there was a transfer intensification downwards of atmospheric masses. A maximum of ozone content increase in the atmosphere column occurred 1 - 3 days after the precipitations and it was ~ 7 - 9% of the initial value of $[O_3]$ (SKRYABIN et al., 1977).

Calculation Method

To find a "pure" contribution of precipitating electrons into the mesospheric ozone content, the polar night conditions are considered, i.e., the time when the short wave radiation of the Sun is absent. It is interesting to determine a maximum increase of ozone content in the mesosphere under the influence of precipitating electrons.

It is known that under precipitation conditions in the mesosphere O atoms are generated. Thus, it is shown (SOCHNEV, 1977) that their formation velocity is determined by the total velocity of ionoformation q(t) and by concentration of the atmosphere components at given height (H):

$$Q(t) = \frac{3.22[N_2] + 4[O_2] + 1.12[O]}{1.15[N_2] + 1.5[O_2] + 0.56[O]}\, q(t). \qquad (1)$$

The electron flux with the exponential energy spectrum is considered here:

$$f(E) = A(t) \cdot \exp(-E/20), \qquad (2)$$

where A(t) is a coefficient which takes into account a temporal change of precipitating electron flux magnitude and reaches 10^9 in maximum, t is time in seconds. It is natural that such huge fluxes cannot exist for a long time but they can occur repeatedly within a day. As a result, such precipitation splashes in the auroral zone can last in total several tens of minutes. Let us assume that

$$A(t) = B \cdot t \cdot \exp\left(-t^2/c\right), \tag{3}$$

where B and C are constants being $5.5 \cdot 10^6$ and 180000, respectively. At these values A(t) reaches its maximum value (10^9 cm^{-2} s^{-1} keV^{-1}) in 5 min. The average precipitation time in this case will be ~ 6 min.

Atomic oxygen disappears in general in the following reactions (McEWAN and PHILLIPS, 1975; CHAMBERLAIN, 1978):

$$O + O + M \rightarrow O_2 + M, \quad \kappa_1 = 3.6 \cdot 10^{-31} \cdot \frac{1}{T} \cdot \exp\left(-\frac{170}{T}\right), \text{cm}^6/\text{s}, \tag{4}$$

$$O + O_2 + M \rightarrow O_3 + M, \quad \kappa_2 = 1.1 \cdot 10^{-34} \cdot \exp\left(\frac{510}{T}\right), \text{cm}^6/\text{s}, \tag{5}$$

$$O + O_3 \rightarrow 2O_2, \quad \kappa_3 = 1.1 \cdot 10^{-11} \exp\left(-\frac{2150}{T}\right), \text{cm}^3/\text{s}, \tag{6}$$

here M is any third particle, K_1, K_2, K_3 are velocity constants of the appropriate reactions.

The reactions (4-6) take place in the atmosphere continuously. Hence, there are the recovery processes of [O], [O_2] and [O_3] which are taken to be constant at the given height and they are equal to the change velocity of these air components obtained from (4-6) under quiet conditions. These velocities are denoted by D(O), D(O_2) and D(O_3).

The equations describing the distribution of oxygen components with the account of the transfer processes are as follows (SOSIN, 1985):

$$\frac{\partial[\Delta O]}{\partial t} = Q(t) + D(O) - 2\kappa_1[O]^2[M] - \kappa_2[O][O_2][M] - \kappa_3[O][O_3] +$$

$$+ \frac{\partial}{\partial z}\left\{(D+K)\frac{\partial[\Delta O]}{\partial z} + \left(\frac{D+K}{T}\cdot\frac{dT}{dz} + \frac{D}{H_O} + \frac{K}{H_{av}} + v\right)[\Delta O]\right\}, \tag{7}$$

$$\frac{\partial[\Delta O_2]}{\partial t} = D(O_2) - \frac{Q(t)}{2} + 2\kappa_3[O][O_3] + \kappa_1[O]^2[M] - \kappa_2[O][O_2][M] +$$

$$+ \frac{\partial}{\partial z}\left\{(D+K)\frac{\partial[\Delta O_2]}{\partial z} + \left(\frac{D+K}{T}\cdot\frac{dT}{dz} + \frac{D}{H_{O_2}} + \frac{K}{H_{av}} + v\right)[\Delta O_2]\right\}, \tag{8}$$

$$\frac{\partial[\Delta O_3]}{\partial t} = D(O_3) + K_2[O][O_2][M] - K_3[O][O_3] +$$

$$+ \frac{\partial}{\partial z}\left\{(D+K)\frac{\partial[\Delta O_3]}{\partial z} + \left(\frac{D+K}{T}\cdot\frac{dT}{dz} + \frac{D}{H_{O_3}} + \frac{K}{H_{av}} + V\right)[\Delta O_3]\right\}, \quad (9)$$

here $[\Delta O]$, $[\Delta O_2]$ and $[\Delta O_3]$ are increments of O, O_2, and O_3 concentrations with respect to their initial contents before the precipitation, T is the temperature by an absolute scale in winter (KASTING, 1981), H_O, H_{O2}, H_{O3}, and H_{av} are the homogeneous atmosphere heights for O, O_2, O_3 and for the component with the average molecular mass, respectively. To find the average molecular mass the atmosphere was considered to consist of N_2, O_2, O_3 and O molecules. The concentration values at heights ≥ 80 km are taken according to (KASTING, 1981). At heights < 80 km the night concentrations of N_2, O_2, and O_3 were used on(McEWAN and PHILLIPS, 1975) and of O on (HUNT, 1973). The transfer coefficients D, K, and V were taken from CHAMBERLAIN (1978); LETTAN (1951); McEWAN and PHILLIPS (1975). The calculations were carried out by the method of probabilistic transitions (SKRYABIN, 1985) for the transfer parameters 0.5 K; 0.5 D; 0.5 V and 2 K, 2 D, 2 V.

Discussion

In Figure 1 the simulation results of $[\Delta O]$, $[\Delta O_2]$ and $[\Delta O_3]$ at various times after the electron precipitation in a form of 6-min splash are presented. From the figure it is seen that when the transfer parameters increase causing the intensification of the air mass displacement downwards, the $[\Delta O]$ decreases and the $[\Delta O_3]$ increases. In Figure 2 the changes of $[\Delta O]$ and $[\Delta O_3]$ in the atmosphere column are presented. With the change of transfer parameters by 0.5, once and twice the maximum values of $[\Delta O_3]$ are $2\cdot10^{15}$, $5\cdot10^{15}$, and $9\cdot10^{15}$ cm^{-2}, respectively. It equals the change of ozone content from a quiet level by 0.3, 0.76, and 1.4%. For 30-min precipitation they will be 1.5, 3.8, and 7%. And the higher is the arrival velocity of the air masses into the lower layer, the earlier is reached the content maximum of $[\Delta O_3]$. As is seen, such changes of ozone content by the order of magnitude correspond to the experimentally obtained effects (SKRYABIN et al., 1977).

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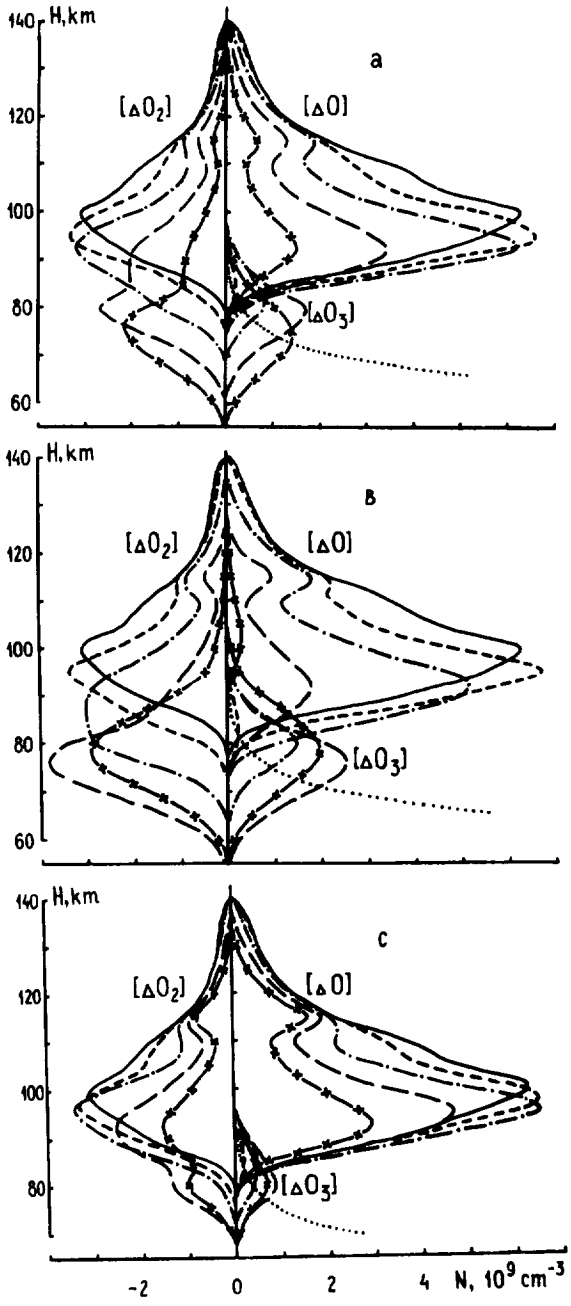

Figure 1 Distributions of $[\Delta O]$, $[\Delta O_2]$ and $[\Delta O_3]$ on heights at various times:

_____ 30 min
- - - - - - - - - - 6 hours
__ · __ · __ 1 day
__ __ __ 3 days
__ x __ x __ 6 days
. . . . . total content of ozone in the upper atmosphere on CIRA 72 model.

a) Coefficients of the turbulent (K), molecular (D) diffusions and the velocity of the averaged vertical wind in winter (V) according to CHAMBERLAIN, 1978; LETTAN, 1951; McEWAN and PHILLIPS, 1975);.
(b) K, D and V are twice increased;
(c) K, D and V are twice decreased.

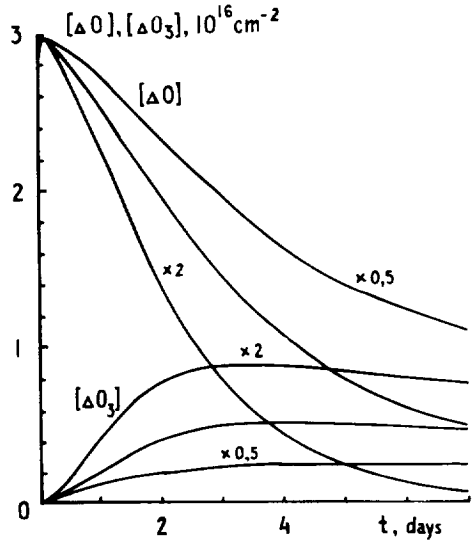

Figure 2. The content of $[\Delta O]$ and $[\Delta O_3]$ in the atmosphere column a single cross section versus time. Figures on curves show K, D and V increase.

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